01-27-00

A

Attorney's Docket No. SEA5112

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Box Patent Application
Assistant Commissioner for Patents
Washington, D.C. 20231

NEW APPLICATION TRANSMITTAL

Transmitted herewith for filing is the patent application of

Inventor(s): John F. Heanue, John H. Jerman and Jeffrey P. Wilde

WARNING: Patent must be applied for in the name(s) of all of the actual inventor(s) 37 C.F.R. § 1.41(a) and 1.53(b).

For (title): "WIDELY TUNABLE LASER"

CERTIFICATION UNDER 37 CFR 1.10

I hereby certify that this New Application Transmittal and the documents referred to as enclosed therein are being deposited with the United States Postal Service on this date January 26, 2000, in an envelope as "Express Mail Post Office to Addressee" Mailing Label Number EL486837633US, addressed to the: Assistant Commissioner for Patents, Washington, D.C. 20231.

Virginia Silva
(Type or print name of person mailing paper)

Virginia Silva
Signature of person mailing paper

1. Type of Application
This new application is for a(n)

☒ Original (nonprovisional)
☐ Design
☐ Plant
☐ Divisional
☐ Continuation
☐ Continuation-in-part (C-I-P)

2. Benefit of Prior U.S. Application(s) (35 USC 119(e), 120, or 121)

☒ The new application being transmitted claims the benefit of prior U.S. application(s) and enclosed are ADDED PAGES FOR NEW APPLICATION TRANSMITAL WHERE BENEFIT OF PRIOR U.S. APPLICATION (S) CLAIMED.

3. Papers Enclosed Which Are Required for Filing Date Under (37 CFR 1.53(b) **(Regular) or 37 CFR 1.153(Design) Application**

Pages of specification: 17
Pages of claims: 2
Pages of Abstract: 1
Sheets of drawing: 10

☐ formal
☒ informal

4. Additional papers enclosed

☐ Preliminary Amendment
☒ Information Disclosure Statement (37 CFR 1.98)
☒ Form PTO-1449
☐ Citations
☐ Declaration of Biological Deposit
☐ Authorization of Attorney(s) to Accept and Follow Instructions from Representative
☐ Other

5. Declaration or oath
☒Enclosed
Executed by:
☒ Inventor(s).
☐ Legal representative of inventor(s). 37 CFR 1.42 or 1.43.
☐ Joint inventor or person showing a proprietary interest on behalf of inventor who refused to sign or cannot be reached.
☐ This is the petition required by 37 CFR 1.47 and the statement Required by 37 CFR 1.47 is also attached. See item 13 below for fee.
☐ Application is made by a person authorized under 37 CFR 1.41 (c) on behalf of all the above named inventor(s).

☐ Not Enclosed.

6. **Inventorship Statement**

The inventorship for all the claims in this application are:

☐ The same.

or

☐ Not the same. An explanation, including the ownership of the various claims at the time the last claimed invention was made,

☐ is submitted.

☐ will be submitted.

7. **Language**

☒ English

☐ Non-English

☐ The attached translation is a verified translation.37 CFR 1.52(d).

8. **Assignment**

An assignment of the invention to Seagate Technology, Inc.

☒ is attached. A separate ☒ "COVER SHEET FOR ASSIGNMENT (DOCUMENT) ACCOMPANYING NEW PATENT APPLICATION" OR☐ FORM PTO 1595 is also attached.

☐ will follow.

9. **Fee Calculation (37 CFR 1.16)**

A. ☒ Regular application

CLAIMS AS FILED				
Number filed	Number Extra	Rate	Basic Fee CFR 1.16(a)	$690.00
Total Claims (37 CFR 1.16(c)) 20-20=	0	x $ 18.00=		00.00
Independent Claims (37 CFR 1.16(b)) 3-3=	0	x $78.00=		00.00
Multiple dependent claim(s), if any (37 CFR 1.16(d))		+ $260.00=		

☐ Amendment canceling extra claims enclosed.

☐ Amendment deleting multiple-dependencies enclosed.

☐ Fee for extra claims is not being paid at this time.

Filing Fee Calculation $690.00

10. Small Entity Statement(s)

☐ Verified Statement(s) that this is a filing by a small entity under 37 CFR 1.9 and 1.27 is (are) attached.

(complete the following, if applicable)

☐ Status as a small entity was claimed in prior application ____/_______________ filed on ___________, from which benefit is being claimed for this application under:
35 U.S.C. ☐119(e),
35 U.S.C. ☐120,
35 U.S.C. ☐121,
35 U.S.C. ☐365(c),
and which status as a small entity is still proper and desired.

☐ A copy of the verified statement in the prior application is included.
☐ Filing Fee Calculation (50% of A, B or C above) $_____

11. Request for International-Type Search (37 CFR 1.104(d)) (complete, if applicable)

☐ Please prepare an international-type search report for this application at the time when national examination on the merits takes place.

12. Fee Payment Being Made at This Time

☐ Not Enclosed
☐No filing fee is to be paid at this time.
(This and the surcharge required by 37 CFR 1.16(e) can be paid subsequently.)

☒ Enclosed
☒ Basic filing fee $690.00
☒ Recording assignment ($40.00; 37 CFR 1.21 (h)) $ 40.00
(See attached "COVER SHEET FOR ASSIGNMENT ACCOMPANYING NEW APPLICATION".)
☐ Petition fee for filing by other than all the inventors or person on behalf of the inventor, inventor refused to sign or cannot be reached. $_____
($130.00; 37 CFR 1.47 and 1.17(h)) $_____
☐ For processing an application with a specification in a non-English language. ($130.00; 37 CFR 1.52(d) and 1.17(k)) $_____
☐ Processing and retention fee $_____
($130.00; 37 CFR 1.53(d; and 1.21 (I)) $
☐ Fee for international-type search report $_____
($40.00; 37 CFR 1.21 (e)) $

☒ Total fees enclosed $ 730.00

13. Method of Payment of Fees

☐ Check(s) in the amount of $__________
☒ Charge Account No. 50-0372 in the amount of $730.00

14. Authorization to Charge Additional Fees

The Commissioner is hereby authorized to charge the following additional fees by this paper and during the entire pendency of this application to Account No. 50-0372

☒ 37 CFR 1.16(a), (f) or (g) (filing fees)
☒ 37 CFR 1.16(b), (c) and (d) (presentation of extra claims)
☒ 37 CFR 1.16(e) (surcharge for filing the basic filing fee and/or declaration on a date later than the filing date of the application)
☒ 37 CFR 1.17 (application processing fees)
☒ 37 CFR 1.18 (issue fee at or before mailing of Notice of Allowance, pursuant to 37 CFR 1.311 (b))

15. Instructions as to Overpayment

☒ Credit Account No. 50-0372
☐ Refund

16. Pages Added

☐ Incorporation by reference of added pages

☒ Plus Added Pages for New Application Transmittal Where Benefit of Prior U.S. Application(s) Claimed-pages added 1.
☐ Plus Added Pages for Papers Referred to in Item _.
☒ Plus "Assignment of Invention"-pages added 5 (including cover sheet and witness pages).

☐ Statement Where No Further Pages Added
(If no further pages form a part of this Transmittal, then end this Transmittal with this page and check the following item.)
☒ This transmittal ends with this page.

(SIGNATURE OF ATTORNEY/AGENT)

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Attorney's Docket No.:SEA5112

ADDED PAGES FOR APPLICATION TRANSMITTAL WHERE BENEFIT OF PRIOR U.S. APPLICATION(S) CLAIMED

17. 35 U.S.C. 119(e)

☐ Amend the specification by inserting, before the first line, the following sentence:
☒ This application claims the benefit of U.S. Provisional Application(s) No(s)

Application No.: 60/154,899
Title: "A WIDELY-TUNABLE DIODE LASER FOR TELECOMMUNICATIONS APPLICATIONS"
Filing Date: 20 September 1999
Attorney Docket No.: SEA5112.01

Application No.: 60/167,951
Title: "MICROACTUATOR FOR TUNABLE LASER"
Filing Date: 29 November 1999
Attorney Docket No.: SEA 5122.01

Application No.: 60/167,937
Title: "MODULATION OPTIONS FOR A WIDELY-TUNABLE DIODE LASER"
Filing Date: 29 November 1999
Attorney Docket No.: SEA 5124.01

18. 35 U.S.C. 120, 121 and/or 365(c)

☐ Amend the specification by inserting, before the first line, the following sentence:
☐ This application claims the benefit of U.S. Patent Application(s) No(s)

Widely Tunable Laser

Related Applications

The present invention is related to, and claims priority from, Provisional Applications S.N. 60/154,899 filed on 9/20/99; and S.N. 60/167,951 filed on 11/29/1999; and S.N. 60/167,937 filed on 29 November 1999, which are incorporated herein by reference.

Field of the Invention

The present invention is applicable to the field of tunable lasers and is more specifically applicable to a tunable laser for use in telecommunications.

Introduction

In telecommunications networks that utilize wavelength division multiplexing (WDM), widely tunable lasers enable transmission of information at different wavelengths. Many proposed network configurations require transmitters that can be tuned to transmit at any of N distinct wavelengths. Even in networks where the individual transmitter wavelengths are held fixed, tunable sources are desirable for maintaining stability of the wavelength. Also, because the same part can be used for any channel, a tunable transmitter is useful from an inventory control perspective.

One prior art tunable laser design uses an external optical cavity, which is illustrated in US Patent 5,771,252. A basic configuration from Patent 5,771,252 is shown in Figure 1 of the present application. Figure 1 shows a laser diode used in combination with a diffraction grating and rotating mirror to form an external optical cavity. In this configuration the grating is fixed. As the mirror is rotated, the light propagating within the optical cavity is fed back to the laser diode. The feedback causes the laser diode to "lase" with a changeable frequency that is a function of the rotation angle of the mirror. Unless accounted for, the frequency of the laser may "mode hop" due to the distinct, spatial longitudinal modes of the optical cavity. It is desirable that the longitudinal mode spectrum of the output beam of the laser diode change without discontinuities. This condition may be satisfied by careful selection of the pivot point about which the mirror is rotated, whereby both the optical cavity length and the grating feedback angle can be scanned such that the single pass optical path length of the external

optical cavity is equal to the same number of half-wavelengths available across the tuning range of the laser cavity. If this condition is satisfied, rotation of the mirror will cause the frequency of the output beam to change without discontinuities and at a rate corresponding to the rotation of the mirror. U.S. Patent 5,319,668 also describes a tunable laser. Both Patent 5,771,252 and Patent 5,319,668 disclose an expression for an optical cavity phase error, which represents the deviation in the number of wavelengths in the cavity from the desired constant value as a function of wavelength. The expression for optical cavity phase error includes terms related to the dispersion of the laser and other optical elements. Patent 5,771,252 teaches a pivot point whereby the cavity phase error and its first and second derivatives with respect to the wavelength all go to zero at the center wavelength. For all practical purposes, the two methods describe the same pivot point.

The grating-based external cavity tunable laser (ECLs) of 5,771,252 is a relatively large, expensive device that is not suitable for use as a transmitter in a large-scale WDM network. Because of the size and distance between components, assembly and alignment of the prior art ECL above is difficult to achieve. Known prior art ECLs use stepper motors for coarse positioning and piezoelectric actuators for fine positioning of wavelength selective components. Because piezoelectric actuators exhibit hysteresis, precise temperature control is needed. In addition, prior art ECL lasers are not robust in the presence of shock and vibration.

Another prior art tunable laser design utilizes a Vertical-Cavity Surface-Emitting Laser (VCSEL). In one embodiment of this device, a MEMS (micro-electro-mechanical-system) mirror device is incorporated into the structure of the VCSEL and is used to tune the wavelength of the laser. Wide tuning range has been demonstrated in such devices for operation around 830 nm, but so far, the development of a reliable, high performance VCSEL at 1550 nm has proved elusive. This device is very difficult to build because the MEMS device must be physically incorporated into the structure of the VCSEL. Furthermore, development of the MEMS actuators in InP-based materials is a formidable challenge.

In other prior art, angular motors have been used in angular gyroscopes and as fine tracking servo actuators for magnetic heads for disk drives. In "Angular Micropositioner for Disk Drives," D. A. Horsley, A. Singh, A.P. Pisano, and R. Horowitz, Proceedings of the 10^{th} Int. Workshop on Micro Electro Mechanical Systems, 1997, p. 454-458, a deep polysilicon device is described with radial flexures extending from a central fixed column, and radial, parallel plate electrodes that effect

rotation of less than 0.5 degree. Batch Fabricated Area Efficient Milli-Actuators, L.-S. Fan, et. al., Proceedings 1994 Solid State Sensor and Actuator Workshop, Hilton Head, p. 38-42 shows a rotary flexural actuator with what appears to be 2 central flexures from central supports; the rotational range is not given but appears to be small. Dual Axis Operation of a Micromachined Rate Gyroscope, T. Juneau, A.P. Pisano, and J.H. Smith, Proceedings 1997 Int. Conf. On Solid State Sensors and Actuators, V.2, pp. 883-890 describes a polysilicon, surface micromachined gyro, which has 4 radial springs supporting a central circular mass. The springs are supported on the outside, and have a small strain relief feature. The angular drive range is not specified, but appears to be small. All of these prior art devices provide limited angular range. These prior art devices completely fill a circular area in a plan view, thus making it difficult or impossible to arrange such an actuator to provide a remote pivot location, as is required by ECLs.

Tunable Distributed Bragg Reflector (DBR) lasers are currently commercially available, however, these lasers have a limited tuning range. Total tuning of about 15 nm and continuous tuning without mode hops over about 5 nm range is typical.

A tunable laser based on sampled grating DBR technology is presently available. The DBR device is tunable over about 50 nm, but the fabrication is difficult and the control electronics are complex, requiring four different control currents.

Another prior art approach to making a tunable laser is to fabricate multiple Distributed Feedback (DFB) lasers on a single chip and couple them together with an arrayed waveguide structure. Each DFB is fabricated with a slightly different grating pitch so that each lases at a slightly different wavelength. Wavelength tuning is accomplished by activating the laser that matches the particular wavelength of interest. The main problems with this approach are cost and insertion loss. Furthermore, fabrication of multiple lasers on the same chip with different operating wavelengths may require direct e-beam writing of the gratings. Also, if one wants to cover a very wide tuning range, the number of lasers required is prohibitively large. Additionally, the multiple laser approach is lossy because coupling N lasers together into one output waveguide results in an efficiency proportional to 1/N.

What is needed, therefore, is a tunable laser that provides advantages over the prior art.

Summary of the Invention

The present invention comprises a tunable laser assembly. Advantages derived from the present invention include: the ability to use commonly available inexpensive Fabry-Perot (FP) laser diodes; high operating frequencies; reduced size and mass, thermal and mechanical stability; precise alignment of optical components made simple by use of photolithographically-defined features in silicon, high production yields; and simple output frequency control schemes.

The present invention may comprise a tunable laser, including: a source means for providing a light along an optical path with any wavelength selected from a continuous bandwidth of wavelengths; a diffractive element positioned in the optical path and from the source by a first distance to redirect the light; a reflective element positioned in the optical path and from the diffractive element by a second distance to receive the redirected light from the diffractive element, and the reflective element positioned in the optical path and from the diffractive element by the second distance to redirect the light towards the diffractive element; the diffractive element positioned in the optical path and from the source by the first distance to re-direct the light towards the source; and a micro-actuator means for selecting the wavelength from the continuous range of wavelengths by altering the optical path of the light.

The present invention may comprise a laser assembly that includes a source for providing a light along an optical path with any wavelength from a continuous range of wavelengths; a diffractive element positioned in the optical path and from the source by a first distance to redirect the light; a reflective element positioned in the optical path and from the diffractive element by a second distance to receive the redirected light from the diffractive element, and the reflective element positioned in the optical path and from the diffractive element by the second distance to redirect the light towards the diffractive element; the diffractive element positioned in the optical path and from the source by the first distance to re-direct the light towards the source; and a micro-actuator for selecting the wavelength from the continuous range of wavelengths by altering the optical path of the light.

The first distance and the second distance may define an optical path length between the source and the reflective element measured in wavelengths, and wherein the optical path length remains constant over the continuous range of wavelengths.

The micro-actuator may be coupled to the reflective element to displace the reflective element. The displacement may comprise an angular displacement. The angular displacement may occur about a virtual pivot point. The displacement may comprise a translation and a rotation. The micro-actuator may comprise a micro-machined actuator. The micro-machined actuator may be coupled to the reflective element. The reflective element may comprise a retro-reflector. The continuous range of wavelengths may comprise from about 1520nm to about 1560nm. The wavelength may be about 1540nm. The source may comprise a Fabry-Perot laser.

The present invention may also comprise a tunable laser, including: a source means for providing a light along an optical path with any wavelength selected from a continuous bandwidth of wavelengths; a diffractive element positioned in the optical path and from the source by a first distance to redirect the light; a reflective element positioned in the optical path and from the diffractive element by a second distance to receive the redirected light from the diffractive element, and the reflective element positioned in the optical path and from the diffractive element by the second distance to redirect the light towards the diffractive element; the diffractive element positioned in the optical path and from the source by the first distance to re-direct the light towards the source; and a micro-actuator means for selecting the wavelength from the continuous range of wavelengths by altering the optical path of the light.

The present invention may also comprise a method for providing light with any wavelength selected from a continuous range of wavelengths, including the following steps: providing the light along an optical path; providing a diffractive element in optical path to diffract the light; providing reflective element in the optical path to reflect the light; and selecting a particular wavelength of light from the continuous range of wavelengths by altering the optical path through displacement of a micro-actuator.

The method may also include the step of displacing the reflective element with the micro-actuator to alter the optical path.

The method may also include the step of displacing the reflective element by a translation and a rotation.

The method may also include the step of displacing the micro-actuator about a virtual pivot point.

The method may also include the step of selecting the particular wavelength from a continuous range of wavelengths comprising the range from about 1520nm to 1560nm.

Brief Description of the Figures

Figure 1 shows a prior art tunable laser design;

Figure 2 shows a MEMS based widely tunable external cavity laser of the present invention;

Figure 3 shows an alternative embodiment of the present invention;

Figure 4 shows the use of an electro-absorptive modulator in an embodiment of the present invention;

Figure 5 shows an embodiment in which a PSD is used;

Figure 6 shows a second embodiment in which a PSD is used;

Figure 7 shows a third embodiment in which a PSD is used;

Figure 8 shows an embodiment in which a wavelength locker is used;

Figure 9 shows a second embodiment in which a wavelength locker is used;

Figure 10 shows a third embodiment in which a wavelength locker is used;

Figure 11 shows a mask layout of the actuator of the present invention;

Figure 12 shows another mask layout of the actuator of the present invention;

Figure 13 shows a 3d view of the present invention; and

Figure 14 shows a module incorporating the present invention.

Description of the Invention

Referring now to Figure 2, there is seen a preferred embodiment of a micro-electro-mechanical-system (MEMS) based widely-tunable external cavity laser (ECL) of the present invention. Advantages of the present invention over that of the prior art that will be apparent from the description provided below include: the ability to use commonly available inexpensive Fabry-Perot (FP) laser diodes; high operating frequencies; wide operating bandwidth; reduced size and mass, thermal and mechanical stability; precise alignment of optical components made simple by use of photolithographically-defined features in a silicon substrate, high production yields; and simple output frequency control schemes. Other advantages will become apparent from a reading of the following description of the present invention.

In the preferred embodiment, a widely-tunable laser (ECL) **100** of the present invention includes a laser **101**, a collimating lens **102**, a diffraction grating **103**, a reflector **104**, and a MEMS based actuator **105**. In the preferred embodiment, the actuator **105** is a rotary actuator, the laser **101** is a Fabry-Perot laser diode, and the reflector **104** is a retro-reflector. The reflector **104** utilizes a high reflectivity coating on its surface, and the laser **101** utilizes a high-reflectivity coating on its rear facet and an anti-reflection coating on its front facet. In the preferred embodiment, the grating **103** is replicated in glass. The present invention utilizes because the provide several advantages compared to traditional polymer gratings, including: thermal stability; replication and stability using thin substrates; and the ability to be handled, diced, cleaned, etc.

In the present invention, light from the laser **101** is directed through the lens **102** towards the grating **103**, by the grating **103** towards the reflector **104**, by the reflector **104** back towards the grating **103**, and by the grating **103** back towards the laser **101**. The optical path traversed by the light from the laser **101** forms an external cavity, which causes an output beam **150** of the laser **101** to lase at a particular wavelength that is a function of the rotation angle of the reflector **104**. In the exemplary embodiment, the ECL **100** can be tuned over +/- 26 nm with +/- 2 degrees of motion of the actuator **105**. For optimum performance of the ECL **100**, it is desired that the wavelength of the output beam **150** be continuously tunable (i.e., no mode hops occur as the laser **101** is tuned over a range of wavelengths). This condition can be satisfied by selecting a virtual pivot point **108** about which the reflector **104** rotates and/or translates, such that an optical path length of the cavity formed between a rear facet of the laser **101** and the reflector **104** measured in wavelengths remains

constant over the desired tuning range. U.S. Patents 5,319,668 and 5,771,252 disclose methods for calculating a pivot point and are incorporated herein by reference. The two calculations made in these two prior art patents result in pivot point locations that differ by 40 nm. The calculations used in both of these patents are applicable to the present invention because the component and manufacturing tolerances of the present invention are greater than 40 nm. In fact, adequate performance of the present invention may be obtained by choosing a pivot point such that the cavity phase error and only the first derivative go to zero at the center wavelength. This condition gives an approximate location for the pivot point. During assembly, the tuning performance of the present invention can be measured, and the pivot point **108** adjusted in a manner described in further detail below. The virtual pivot point of the present invention allows for a compact geometry and results in a lower-cost device with better optical performance than if a real pivot point was used. Better optical performance is achieved because the compact geometry results in greater spacing of the external optical cavity modes and greater side-mode suppression.

In an exemplary embodiment, the optical path length of the external cavity (a sum of the optical distance between the front facet of the laser **101**, the grating **103**, and the front of the reflector **104**) is approximately 5 mm; and the center wavelength, grating pitch, angle of incidence, and diffraction angle of the grating **103** are 1540 nm, 1050 lines/mm, 85 degrees, and 38 degrees, respectively. Although the overall tuning range of the ECL **100** is a function of the width of the gain curve of the laser **101**, which in the preferred embodiment of the present invention can be tuned over a range on the order of 40 nm, it is understood that a much broader gain profile may be achievable using, for example, a Fabry-Perot strongly-pumped quantum-well laser design, referenced in *Electronics Letters*, Vol. 26, No. 11, pp. 742-743, "External Grating Laser With Wide Tuning Range of 240nm," by Epler *et al.* In the present invention, single-mode operation occurs when the spacing of the external cavity modes are greater than the linewidth of the grating **103**. The linewidth of the grating **103** is determined by the angle of incidence and by the beam size. In an exemplary embodiment, the grating **103** linewidth is about 21 GHz and the external cavity modes are spaced by about 30 GHz. The ultimate linewidth is determined by the external cavity mode spacing and by the quality of the external cavity. In the exemplary embodiment, with high reflectivity coatings on the reflector **104** and on the rear facet of the laser **101**, the linewidth is less than 1 Mhz.

Referring now to Figure 3, and preceding figures and descriptions as needed, there is seen one alternative of the present invention. The present invention identifies that for high data rate telecommunications applications, the output beam **150** of the ECL **100** of Figure 2 could be modulated directly by varying the laser **101** current in accordance with the data stream to be transferred. The present invention identifies that long external optical cavity lengths make it more difficult to modulate the ECL **100** at very high frequencies and that it is, therefore, desirable to keep the external optical cavity length of the ECL as short as possible. As illustrated in Figure 3, it is envisioned that the present invention could be implemented in an alternative embodiment in which the actuator **104** is used to displace the grating **103**. In the alternative embodiment of Figure 3, it is understood that because the grating **103** provides the reflective function of the reflector **103**, the reflector need not be used and the optical cavity length can be reduced over that of the preferred embodiment of Figure 2. However, it is identified that in the alternative embodiment of Figure 3, single-mode operation of the laser **101** is more difficult to achieve than in the preferred embodiment because the there is only a single-pass reflection of the output beam **150** from the grating.

In another alternative embodiment, a Fabry-Perot laser **101** with as high a relaxation oscillation frequency as possible could be used to achieve high data transfer rates. In this embodiment, the laser should preferably maximize the differential gain, maximize the internal photon density, and minimize the photon lifetime. Multiple-Quantum-Well (MQW) lasers provide these characteristics and have been demonstrated to operate with modulation bandwidths well in excess of 10 GHz. See for example *IEEE Photonics Technology Letters*, Vol. 9, No. 3, pp. 306-308, "24-GHz Modulation Bandwidth and Passive Alignment of Flip-Chip Mounted DFB Laser Diodes", by Lindgren, *et al.* With this approach, direct modulation of the ECL **100** as high as 2.5 Gb/sec should be possible.

In yet another alternative embodiment, the ECL **100** could be designed to operate at frequencies corresponding to multiples of longitudinal mode spacing (i.e., multiples grater than the relaxation oscillation frequency). This approach would have the drawback of decreasing the mode spacing and increasing the overall size of the ECL **100**.

Referring now to Figure 4, and preceding figures and descriptions as needed, there is seen an integrated electroabsorptive modulator as used in a preferred embodiment of the present invention. In an alternative embodiment, the present invention identifies that an

electroabsorptive (EA) modulator could also be used to achieve high data transfer rates. At high data rates, however, a decrease in laser modulation response occurs. This decrease can be understood by considering the characteristic lifetimes of photons. Photon lifetime for the laser **101** is given by $1/(c \cdot \alpha)$, where α is the total loss distributed over the equivalent free-space cavity. In a solitary laser, a photon spends all its time in a highly absorbing medium so that the photon lifetime is short. In the ECL **100**, the photon spends a large fraction of the time in loss-less free-space, so the lifetime is proportionally longer. When modulating the ECL **100** at high frequency, it is desirable that the photons disappear when the current is turned off, but, this does not happen fast enough when the photon lifetime is long. The present invention identifies that if short photon lifetime is desired, the EA modulator could be positioned in the external optical cavity as shown in Figure 4. An advantage with this approach is that the EA modulator can be fabricated on the same chip as the laser **101**. Because the EA modulator absorbs photons at a speed corresponding to its modulation frequency, it can be used to overcome the problems associated with long photon lifetime. In an exemplary embodiment, the EA modulator may be used to modulate the output beam **150** at up to 10 Gbits/sec.

Referring now to Figure 5 and preceding figures and descriptions as needed, there is seen an embodiment in which a position sensing detector (PSD) is used for servo-control of the actuator. In the embodiment of Figure 5, a PSD is used to measure the angle of a reference beam of light that is reflected from the reflector **104**. The signal from the PSD is used in a servo loop to set the voltage on the actuator **105**. An advantage of this embodiment is that the wavelength of the reference beam can be matched to the sensitivity of commercially available PSDs.

Referring now to Figure 6 and preceding figures and descriptions as needed, there is seen a third embodiment in which a PSD is used for servo control. In the embodiment of Figure 6, the grating **103** comprises wide enough grooves such that both first and second order diffracted output beams are produced from the beam **150**. Either the first order or the second order beam can be directed to the PSD to find the angle of the reflector **104**.

Referring now to Figure 7, and preceding figures and descriptions as needed, there is seen a second embodiment in which a PSD is used for servo control. In the embodiment of

Figure 7, the first order diffracted beam is reflected from the grating **103** after reflection by the mirror **104** and is measured by a PSD to measure the wavelength of the output beam **150**. The signal from the PSD is used in a servo loop to set the voltage of the actuator **105**. It is understood that in the embodiments of Figures 5-7, the signal from the PSD can also be used for servo control of the power of the laser **101**.

In an alternative embodiment to those of Figures 5-7, a capacitance measurement of the actuator **105** can be used as an indication of the position of the attached reflector **104**. As discussed previously, movement of the reflector **104** determines the output wavelength of the ECL **100**. The present invention identifies that the movement can be measured as a capacitance change in the actuator **105**. In this embodiment, the output wavelength vs. the capacitance of the actuator **105** may be measured, and capacitance sensing electronics comprising a servo-loop may be used to maintain the position of the actuator **105** (and therefore the laser wavelength) fixed over time. This method of servo control can be implemented at low cost and does not require extra optical components. Because the capacitance of the actuator **105** and performance of the capacitance-sensing electronics are temperature dependent, a thermo-electric cooler (TEC) may need to be used to stabilize the temperature of the ECL **100**.

In yet another alternative embodiment to those of Figures 5-7, the wavelength vs. capacitance behavior of the actuator **105** may measured at a number of different temperatures. In this embodiment, a thermistor could be used to measure temperature, which in turn could be used to determine which values to use for servo control. In an exemplary embodiment, a stability of better than 1 part in 1000 is achievable with capacitance sensing.

Referring now to Figure 8 and preceding figures and descriptions as needed, there is seen an embodiment of a wavelength locker as used with the present invention. The present invention identifies that in an alternative approach to that of Figures 5-7, a wavelength locker may be used to stabilize the wavelength of the ECL **100**. For a discussion of wavelength locking techniques, see "Wavelength lockers keep lasers in line," Photonics Spectra, February 1999, pp. 104-110 by Ed Miskovic. Similar techniques can be used to stabilize the wavelength of the present invention. The error signal from the wavelength locker may be used in a servo loop to set the voltage applied to the actuator **105**. In the embodiment of Figure 8, the

wavelength locker is external to the ECL **100** and a monitor signal is split off from the output beam **150** by an optical beam splitter. The disadvantage of this approach is that the output beam **150** intensity is reduced.

Referring now to Figure 9, and preceding figures and descriptions as needed, there is seen another embodiment of a wavelength locker as used with the present invention. In the embodiment of Figure 9, light from the rear facet of the laser **101** is directed to the wavelength locker, which may or may not be located within the ECL **100** itself. In the embodiments of Figure 8 and 9, the present invention identifies that the wavelength locker can also be used to servo control the power of the laser **101**.

Referring now to Figure 10, and preceding figures and descriptions as needed, there is seen another embodiment of a wavelength locker as used with the present invention. In an embodiment in which the wavelength of the output beam **150** of at least one ECL **100** needs to be checked for stability only intermittently, the present invention identifies that a single wavelength calibrator/locker **108** can be shared to maintain a particular wavelength of a particular ECL **100**. In the embodiment of Figure 10, a 1xN switch is used to direct a monitor signal from a ECL **100** to the locker **108**. Elimination of N-1 wavelength calibrators/lockers **108** represents a significant cost saving.

Referring now to Figure 11, and preceding figures and descriptions as needed, there is seen a detailed view of a mask layout for the MEMS based actuator **105** of the present invention.. In the preferred embodiment, rotation of the actuator **105** about the virtual pivot point **108** acts to rotate and translate the mirror **104** such that the external optical cavity is maintained with a constant length over the entire rotation angle of the actuator. The present invention identifies that changes in the geometrical relationship between the components comprising the ECL **100** may change due to temperature and/or mechanical effects and that, in doing so, the optical path length of the external optical cavity and thus the wavelength of the output beam **150** may change. As is discussed below, the actuator **105** is designed to provide a mechanism which compensates for these changes.

In the preferred embodiment, the actuator **105** is manufactured from the mask shown in Figure 11 using well known micro-machining process steps. The actuator **105** comprises: a silicon substrate **121**, two sets of comb drive elements **111**, bars **128**, suspended trusses **125**, suspension beams **110**, a suspended frame **126**, flexural couplers **123**, and a suspended lever **122**. The silicon substrate **121** comprises etched features for receiving the laser **101**, the lens **102**, and the diffraction grating **103**. Each of the comb drive elements **111** comprises two sets of interlocking teeth **127**. The interlocking teeth **127** comprise a plurality of fixed teeth that are coupled by a respective bar **128** to the silicon substrate **121**, and a plurality of movable teeth that are coupled to a respective movable truss **125**. The bars **128** are coupled through respective electrical connections to respective bond pads **129-133**. Although it is preferred that the individual teeth **127** comprising the comb drive elements **111** lie on circumferential arcs centered about the pivot point **108**, it is not necessary for the ends of the teeth **127** to lie along radial lines extending from the center of rotation. The ends of some of the teeth **127** may be arranged to lie along a line that does not pass through the center of rotation, which would allow the bars **128** to be made with added thickness along the ends that point towards the pivot point **108** and yet sufficient electrical isolation air-gap therebetween. Each of the trusses **125** is suspended by respective suspension beams **110**. The suspension beams **110** are coupled to the suspended frame **126**, which is attached at its ends to the substrate **121** by two sets of flexural couplers **123**. One of the flexural couplers **123** serves as an electrical ground connection to the upper bond pad **129**. The other flexural coupler is attached to the suspended lever **122**. The trusses **125**, the suspensions **110**, the frame **126**, and the lever **122** are all suspended above the substrate **121**. The reflector **104** is attached to a slot in one of the trusses **125** by a mating post, springs, adhesive, solder, or similar attachment means. In the exemplary embodiment, the reflector **104** is about 2 mm long by 400 um high. A reflective surface of the reflector **104** is perpendicular to the horizontal plane of the actuator **105**. The mass and size of the reflector **104** is taken into account by the design of the actuator **105**, which is designed to maintain mechanical stability.

In the preferred embodiment, a potential applied to bond pads **131** and **133** causes an electro-static potential to be created between the respective fixed and movable teeth of the comb drive elements **111**, which causes the trusses **125** to rotate clockwise about the virtual pivot point **108**. A potential applied to bond pads **130** and **132** causes the trusses **125** to rotate counter-clockwise. In the preferred embodiment, when the lever **122** is moved (for example,

manually or by other movement means such as micro-machined actuator or the like) the coupler **123** that is attached to the lever **122** rotates around a point near its center. The opposite coupler **123** that is not connected to the lever **122** causes the small rotation of the first coupler to be converted into a translational motion along an axis extending through the two couplers. By arranging the couplers **123** to be generally parallel to the optical axis of the external optical cavity, motion of the lever **122** can be used to adjust the external optical cavity length independent of the rotation of the actuator **105**. The adjustments can be made as required to compensate for changes in temperature or variations in the optical cavity length, or to compensate for small offsets in the virtual pivot point **108**.

The present invention takes into consideration that the comb drive elements **111** may become unstable and "snap-over" in the radial direction if the radial stiffness of the suspension beams **110** falls below a value equal to the derivative of the electrostatic force between the comb drive elements **111** with respect to radial motion, and that this instability becomes more severe with large, static angular deflection. Although folded beam suspension designs are known by those skilled in the art to provide large rotational range, they do so with a penalty of reduced out-of-plane and radial stiffness, which would work against the desired goal of maintaining mechanical stability. The present invention identifies a novel and new design that takes into consideration the limitations of folded beam designs and instead utilizes the "straight-beam" suspension beams **110** described above. As described above, the basic structure for the actuator **105** is to use 2 or more suspensions **110** that are radially disposed around the axis of rotation of the actuator **105**. In the preferred embodiment, 2 or 3 beams are used and are spaced 20-30° apart with respect to the rotation axis. It is understood that if larger angles of rotation are desired, the size of the actuator **105** would be increased. In the preferred embodiment, the rotary comb drive elements **111** are arranged around the suspension beams **110**, and can either be contained between the suspension beams, or connected outside the beams. If the comb drive elements **111** are arranged over an arc of about 120°, it may be advantageous to have three suspension beams **110** arranged at 60° spacing.

In the preferred embodiment, the actuator **105** is fabricated from a high aspect ratio process, which can also include plated metal processes, for example, Lithographie, Gavanometrie and Abformung (LIGA) process well known in the art. LIGA processing techniques result in structures that comprise vertical dimensions substantially greater than the horizontal width of the smallest

features of the actuator **105**. With these processes, the resulting stiffness of the actuator **105**, the motion of the actuator may be constrained to be substantially in the plane of the actuator.

Referring now to Figure 12, and preceding figures and descriptions as needed, there is seen a second mask layout for an actuator of the present invention. The layout of Figure 12 is similar to the layout of Figure 11, except that the virtual pivot point **108** location is changed and some aspects of the grating **103** and the angle of the reflector **104** with respect to the grating are slightly different.

Referring now to Figure 13, and preceding figures and descriptions as needed, a 3D view of the present invention including: laser diode **101**, lens **102**, grating **103**, reflector **104**, and output beam **150**, is shown. As seen in Figure 13, the output beam **150** is quite narrow along one axis, but the small incident angle of the beam on the grating **103** causes the diffracted beam to be extended along a perpendicular axis.

Referring now to Figure 14, and preceding figures and descriptions as needed, there is seen a module **106** incorporating the ECL **100**. The ECL **100** comprises a very small size and mass, which enables the use of simple closed-loop methods to control the components to accurately set and hold the wavelength of the output beam **150**. In contrast to the prior art, which may require novel laser structures, such as, for example, a long-wavelength vertical-cavity surface-emitting laser (VCSEL), the present invention can be implemented using a inexpensive Fabry-Perot laser as the laser **101**, which is readily available in large quantities at low prices. Use of a Fabry-Perot laser in the present invention is further beneficial because, unlike VCSELs, they can operate at long operating wavelengths, for example, up to and over 1700 nm, and in particular 1540nm, which is one wavelength currently used by telecommunications equipment.

Because the laser **101** and actuator **105** of the present invention can be made separately, the wafer fabrication processes for their manufacture can be made simpler, which can provide higher manufacturing yields than the prior art.

The present invention identifies that, other than in the embodiment described above in which capacitance sensing is used for servo control, the ECL **100** exhibits sufficient thermal

stability such that a thermo-electric cooler need not be used. This is an advantage because TE coolers can be relatively unreliable and are prone to fail.

Because the rotation angle of the MEMS actuator **105**, and hence the reflector **104**, can be held steady under simple closed loop control, the wavelength of the output beam **150** may also be held steady. Furthermore, unlike prior art tunable VCSELs, in which wavelength vs. actuator voltage must be re-calibrated as the laser ages, the stable dispersive properties of the diffraction grating **103** of the present invention do not change with age, such that after an initial calibration step, further calibration of the module **106** is not necessarily required. Even if in some embodiments the wavelength of the output beam **150** can not be held stable over the lifetime of the module **106**, the wavelength stability of the present invention is good enough such that only intermittent re-calibration is envisioned.

Although, the foregoing discussion has presented particular embodiments of the present invention, it is to be understood that the above description is not to be limited to only the described telecommunications application and embodiments. For example, other applications include: remote sensing or spectroscopy applications. It will also be appreciated by those skilled in the art that it would be possible to modify the size, shape, appearance and methods of manufacture of various elements of the invention, or to include or exclude various elements and stay within the scope and spirit of the present invention. Thus, the invention should be limited only by the scope of the claims as set forth below.

What is claimed is:

1. A laser assembly, comprising:
   a source for providing a light along an optical path with any wavelength from a continuous range of wavelengths;
   a diffractive element positioned in the optical path and from the source by a first distance to redirect the light;
   a reflective element positioned in the optical path and from the diffractive element by a second distance to receive the redirected light from the diffractive element, and the reflective element positioned in the optical path and from the diffractive element by the second distance to redirect the light towards the diffractive element; the diffractive element positioned in the optical path and from the source by the first distance to re-direct the light towards the source; and
   a micro-actuator for selecting the wavelength from the continuous range of wavelengths by altering the optical path of the light.

2. The laser assembly of claim 1, wherein the first distance and the second distance define an optical path length between the source and the reflective element measured in wavelengths, and wherein the optical path length remains constant over the continuous range of wavelengths.

3. The laser assembly of claim 2, wherein the micro-actuator is coupled to the reflective element to displace the reflective element.

4. The laser assembly of claim 3, wherein the displacement comprises an angular displacement.

5. The laser assembly of Claim 4, wherein the angular displacement occurs about a virtual pivot point.

6. The laser assembly of Claim 4, wherein the displacement comprises a translation and a rotation.

7. The laser assembly of Claim 2, wherein the micro-actuator comprises a micro-machined actuator.

8. The laser assembly of Claim 7, wherein the micro-machined actuator is coupled to the reflective element.

9. The laser assembly of Claim 8, wherein the reflective element comprises a retro-reflector.

10. The laser assembly of Claim 2, wherein the continuous range of wavelengths comprises from about 1520nm to about 1560nm.

11. The laser assembly of Claim 10, wherein the wavelength is 1540nm.

12. The laser assembly of Claim 10, wherein the source comprises a Fabry-Perot laser.

13. A tunable laser, comprising:

a source means for providing a light along an optical path with any wavelength selected from a continuous bandwidth of wavelengths;

a diffractive element positioned in the optical path and from the source by a first distance to redirect the light;

a reflective element positioned in the optical path and from the diffractive element by a second distance to receive the redirected light from the diffractive element, and the reflective element positioned in the optical path and from the diffractive element by the second distance to redirect the light towards the diffractive element; the diffractive element positioned in the optical path and from the source by the first distance to re-direct the light towards the source; and

a micro-actuator means for selecting the wavelength from the continuous range of wavelengths by altering the optical path of the light.

14. The tunable laser of Claim 13, wherein the source comprises a Fabry-Perot laser.

15. The tunable laser of Claim 13, wherein the micro-actuator comprises a micro-machined actuator.

16. A method for providing light with any wavelength selected from a continuous range of wavelengths, comprising the following steps:

providing the light along an optical path;

providing a diffractive element in optical path to diffract the light;

providing reflective element in the optical path to reflect the light; and

selecting a particular wavelength of light from the continuous range of wavelengths by altering the optical path through displacement of a micro-actuator.

17. The method of Claim 16, further comprising the step of displacing the reflective element with the micro-actuator to alter the optical path.

18. The method of Claim 16, further comprising the step of displacing the reflective element by a translation and a rotation.

19. The method of Claim 16, further comprising the step of displacing the micro-actuator about a virtual pivot point.

20. The method of Claim 16, further comprising the step of selecting the particular wavelength from a continuous range of wavelengths comprising the range of from about 1520nm to about 1560nm.

Abstract

A Fabry-Perot laser and a micro-actuator are utilized to provide continuous tuning over a range of wavelengths.

5112-00

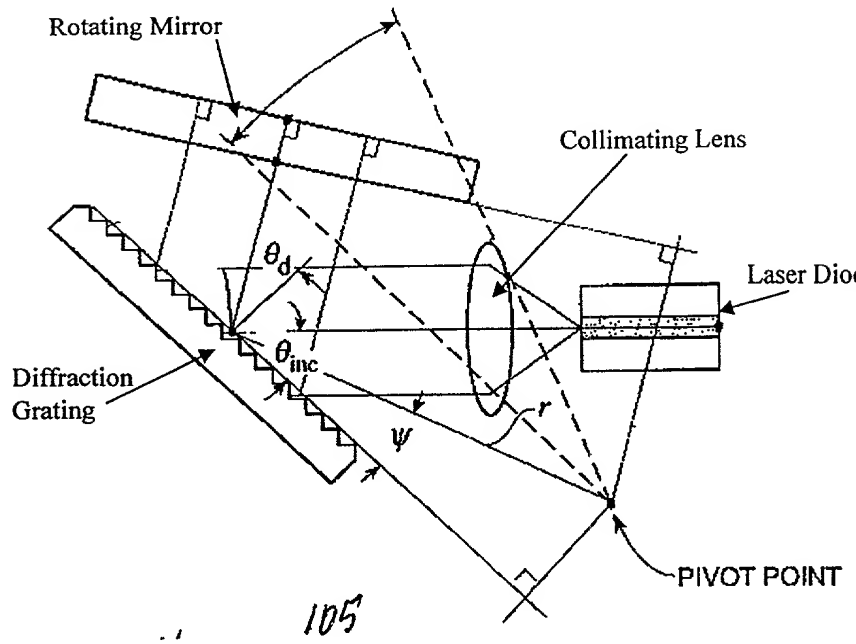


Fig. 1
PRIOR Art

December 17, 1999

100

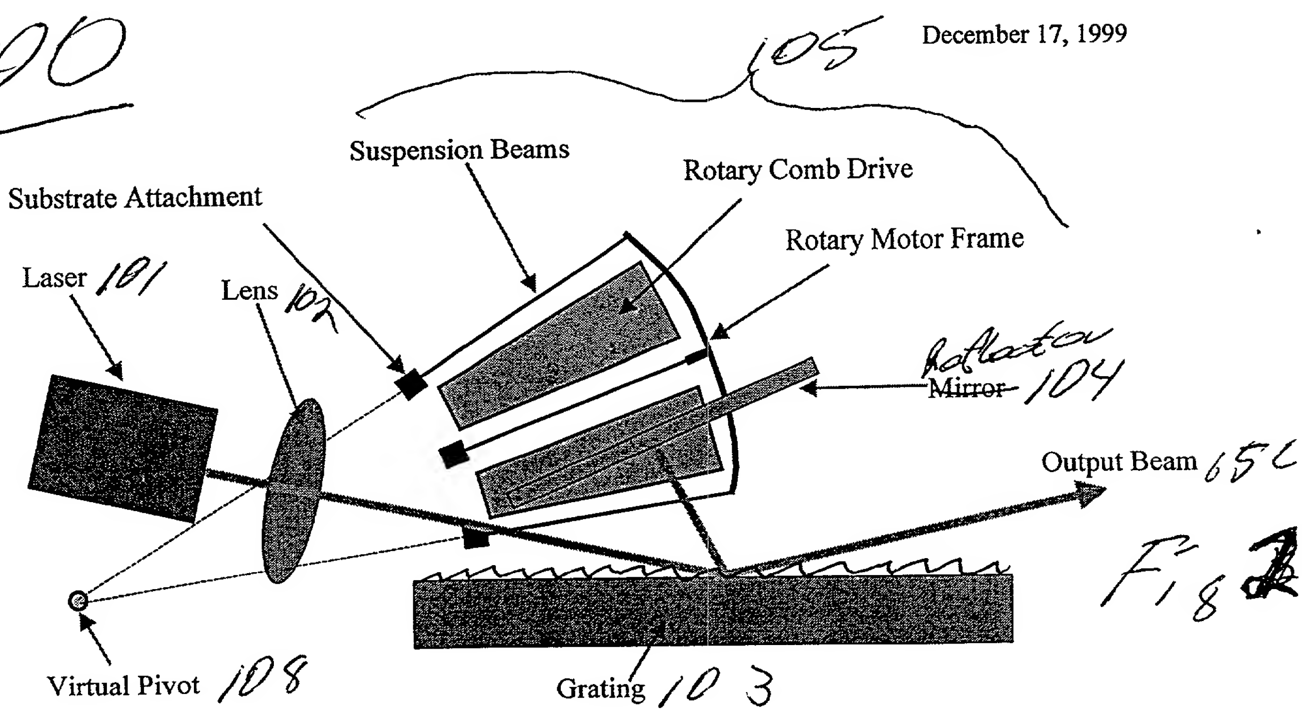


Fig 2

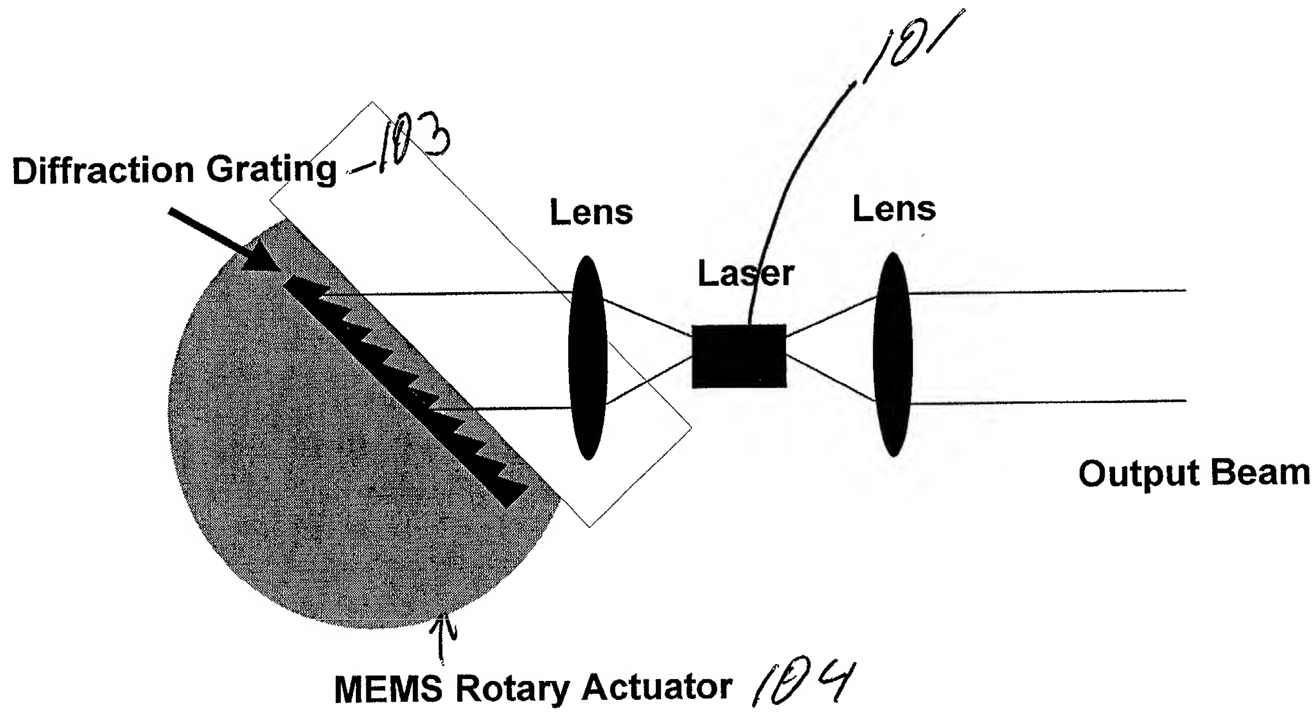

Diffraction Grating
103
Lens
101
Lens
Laser
Output Beam
MEMS Rotary Actuator 104

FIG 3

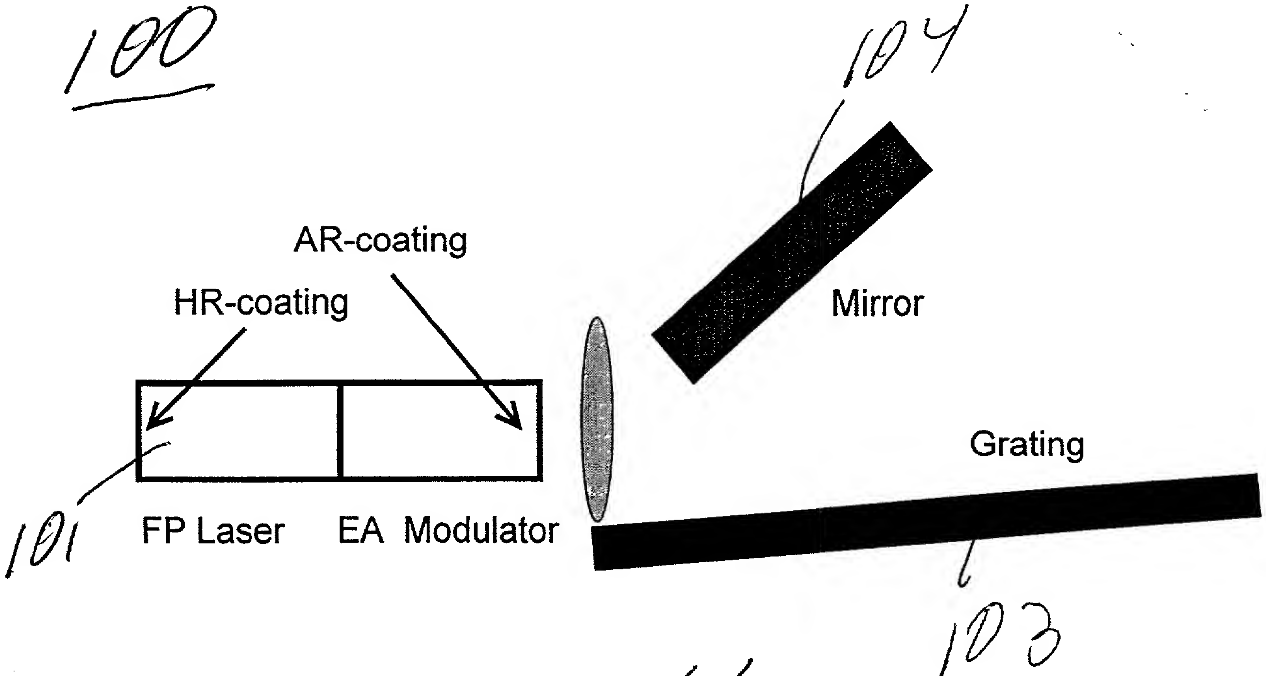

100
104
AR-coating
HR-coating
Mirror
Grating
101
FP Laser
EA Modulator
103

Fig 4

Fig 5

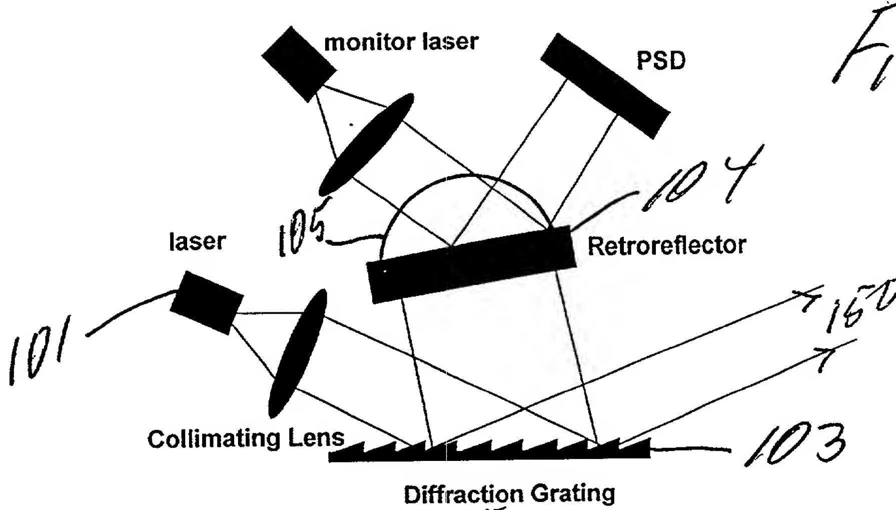


Fig 6

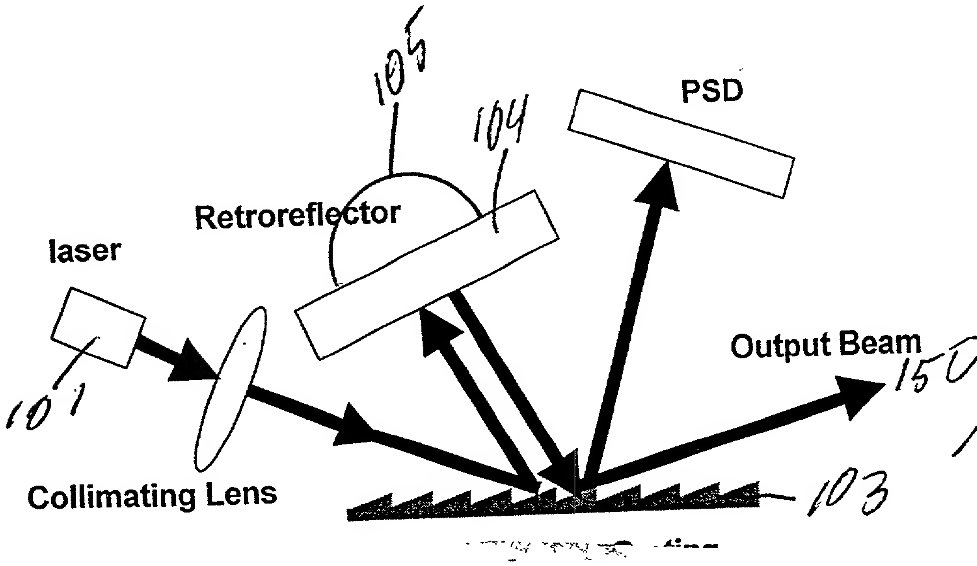
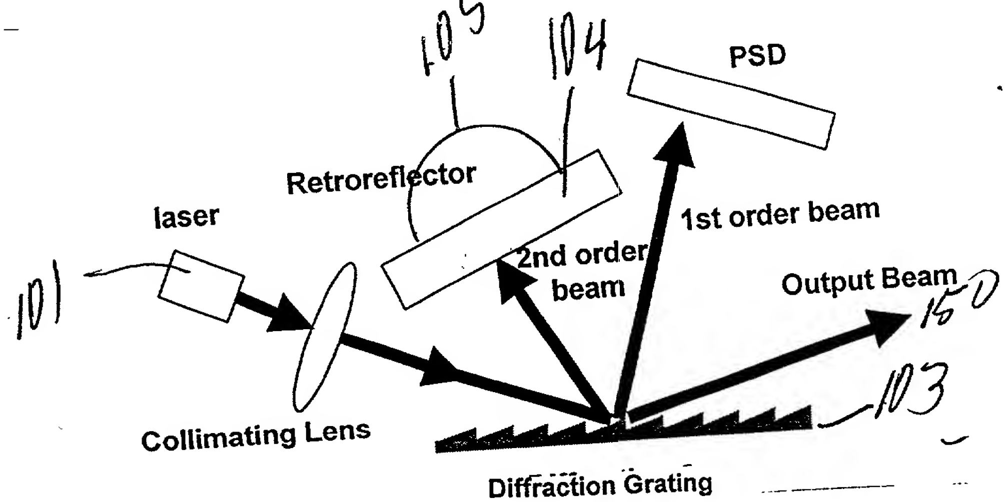


Fig 5

Fig 7



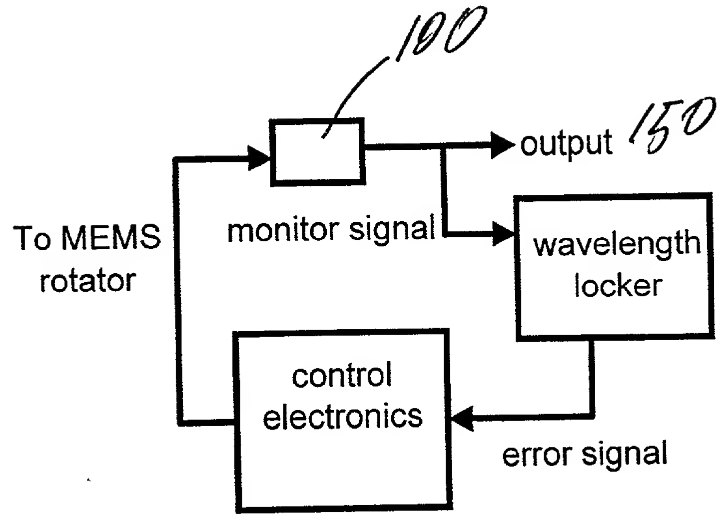


Figure 8

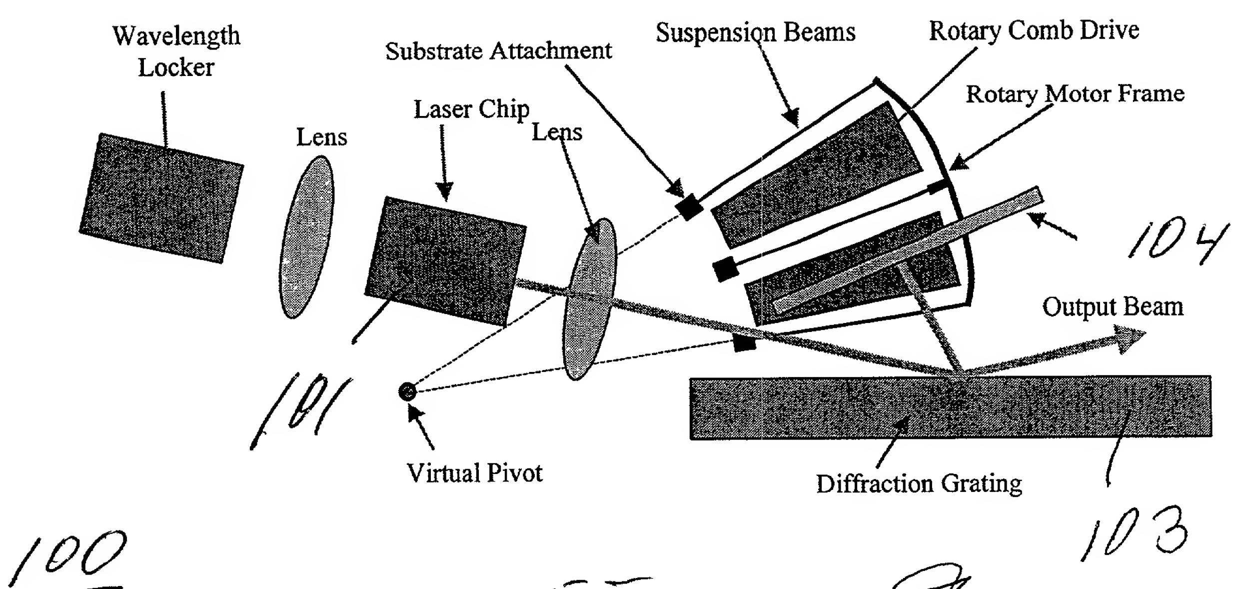


Figure 9

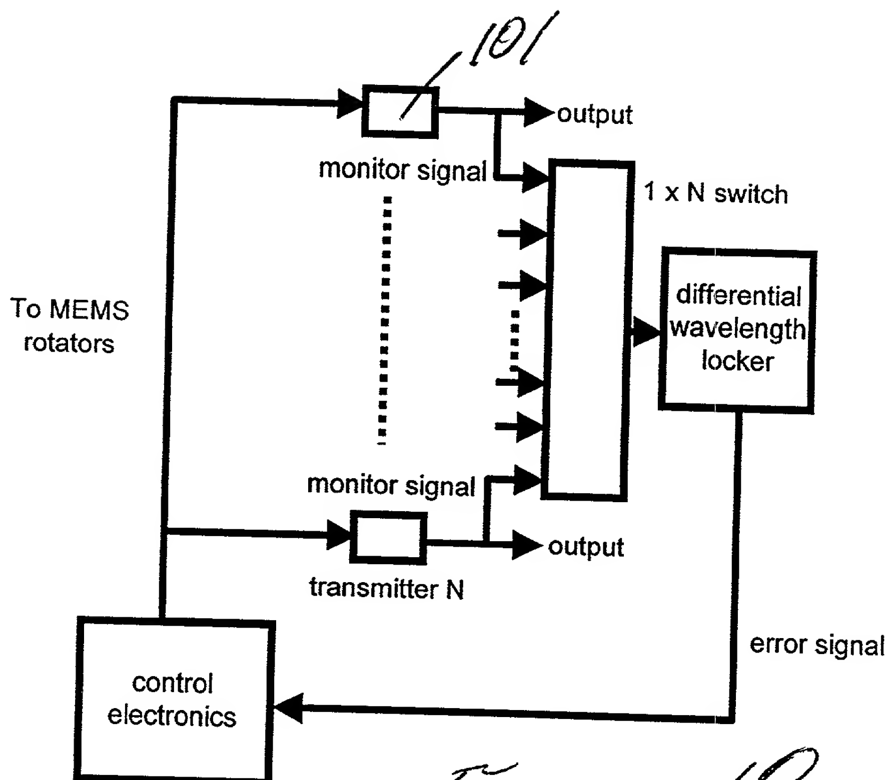

101
output
monitor signal
1 x N switch
To MEMS rotators
differential wavelength locker
monitor signal
output
transmitter N
error signal
control electronics

Figure 10

100

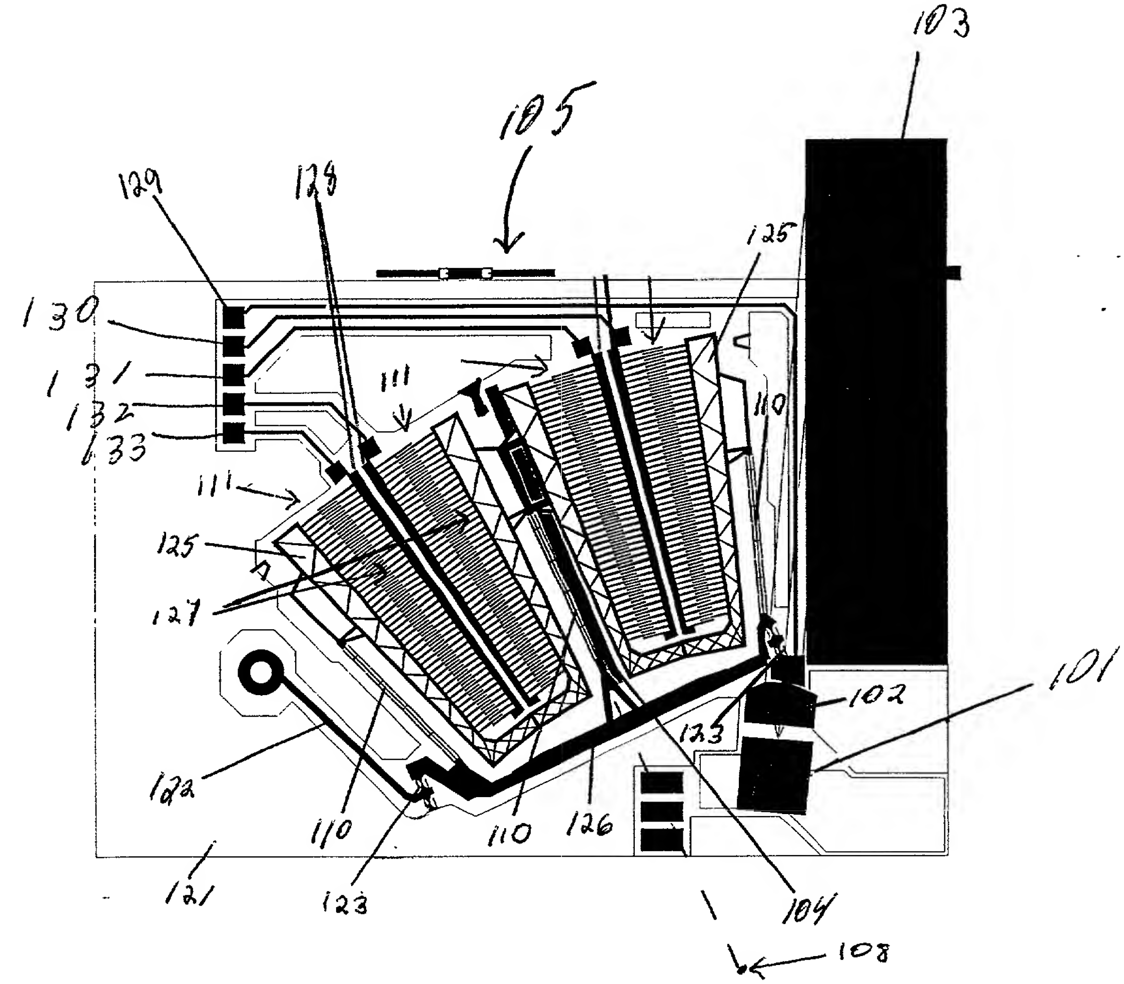

103
105
129
128
125
130
131
132
133
111
111
110
125
127
101
102
123
122
110
110
126
121
123
104
108

Fig 11

100

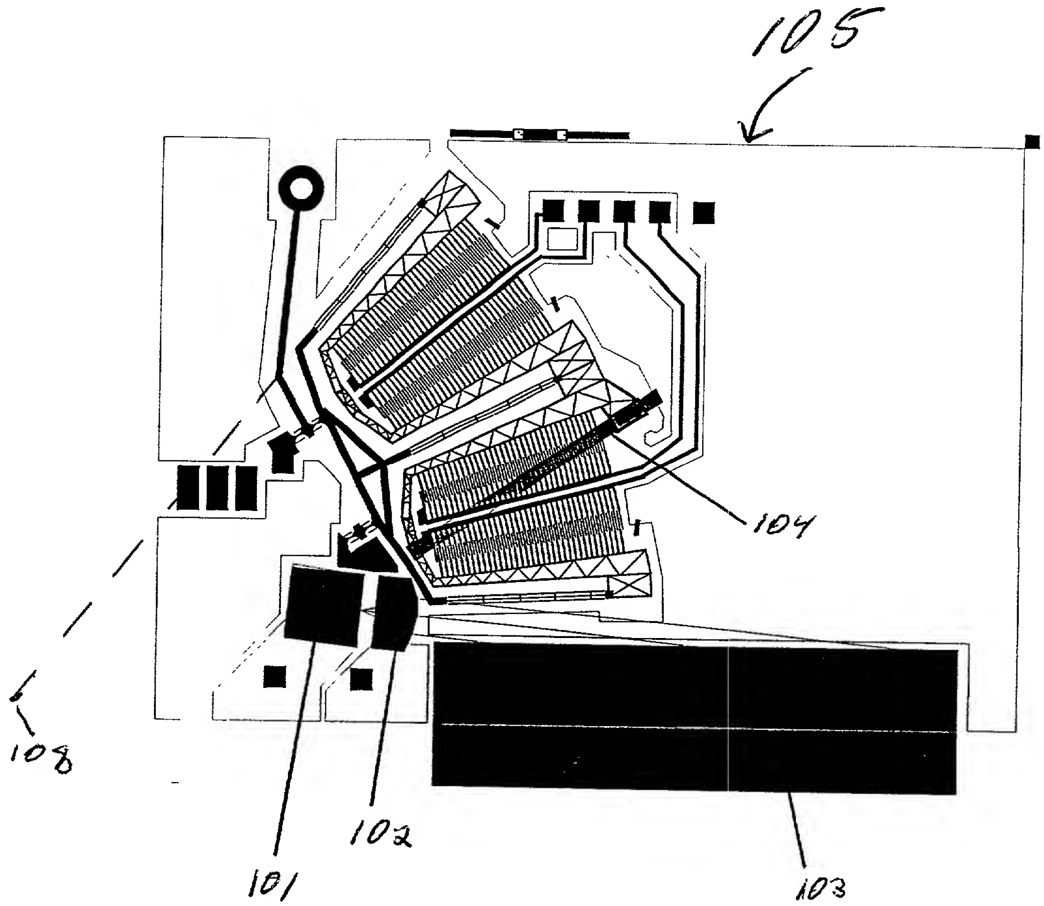


Fig 12

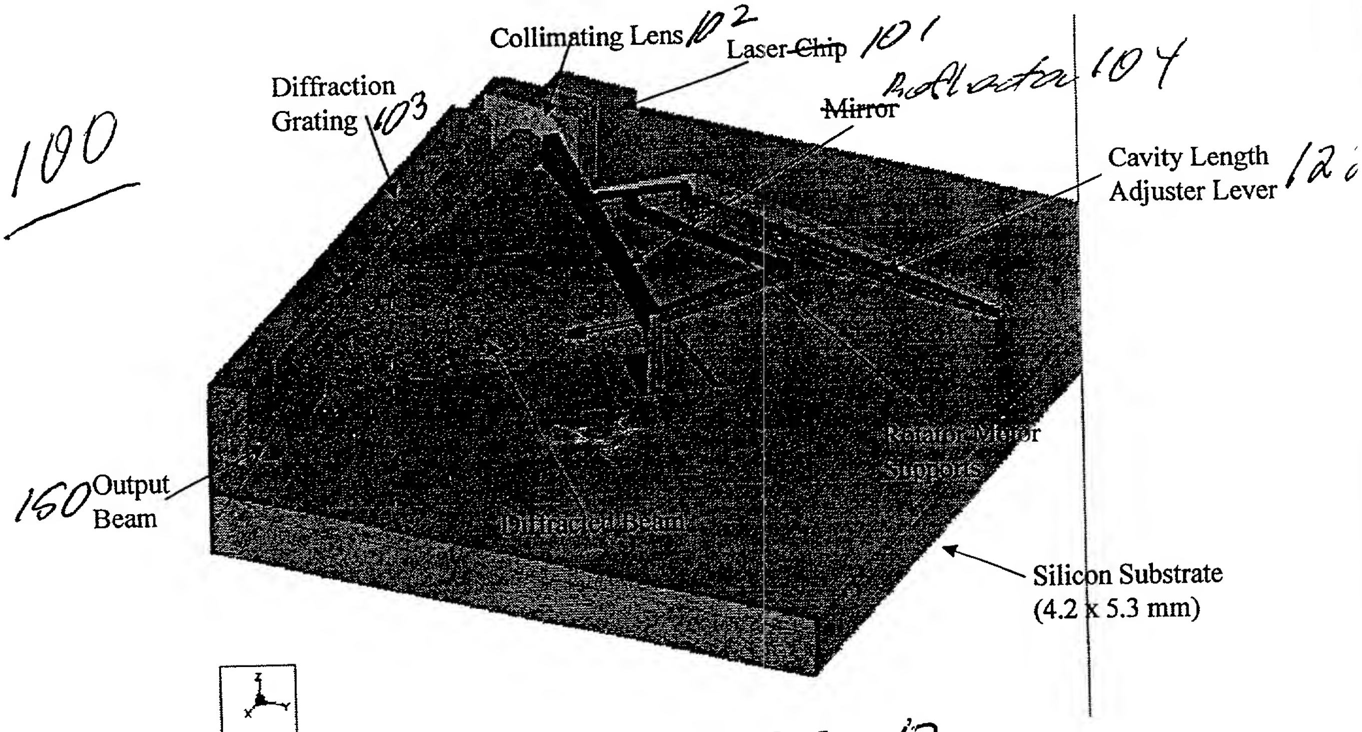

100
Collimating Lens 102
Laser ~~Chip~~ 101
Diffraction Grating 103
~~Mirror~~ Reflector 104
Cavity Length Adjuster Lever 12i
Rotating Motor Supports
160 Output Beam
Diffracted Beam
Silicon Substrate (4.2 x 5.3 mm)

Fig 13

December 17, 1999

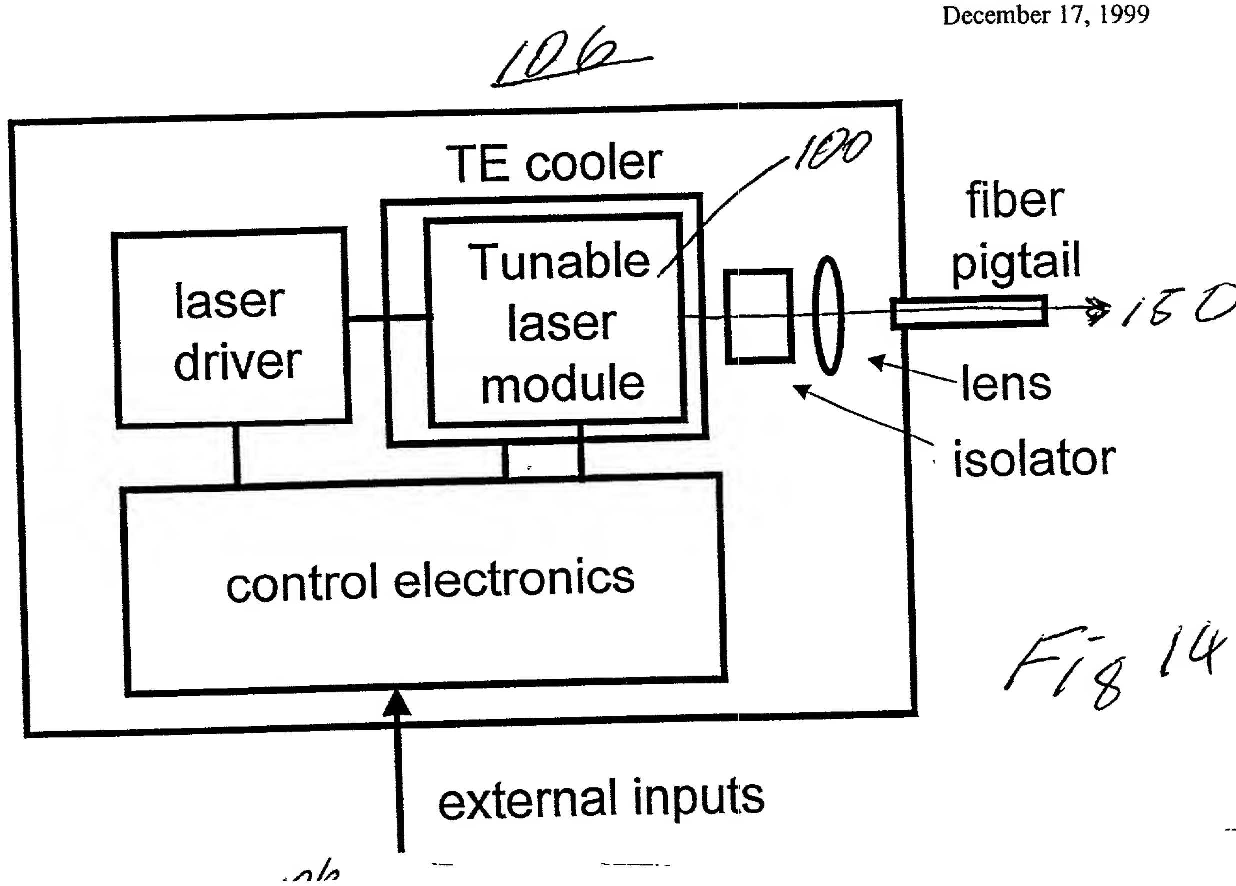


Fig 14

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PTO/SB/01 (12-97)
Approved for use through 9/30/00. OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63)

[X] Declaration Submitted with Initial Filing **OR** [ ] Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

Attorney Docket Number	SEA5112
First Named Inventor	Heanue, John F.
COMPLETE IF KNOWN	
Application Number	
Filing Date	January 26, 2000
Group Art Unit	
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

WIDELY TUNABLE LASER

(Title of the Invention)

the specification of which

[X] is attached hereto

OR

[ ] was filed on (MM/DD/YYYY) [ ] as United States Application Number or PCT International Application Number [ ] and was amended on (MM/DD/YYYY) [ ] (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 356(b) of any foreign application(s) for patent or inventor's certificate, or 356(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]

[ ] Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)
60/154,899	09/20/1999
60/167,951	11/29/1999
60/167,937	11/29/1999

[ ] Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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DECLARATION — Utility or Design Patent Application

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number *(if applicable)*

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02C attached hereto.

As a named inventor, I hereby appoint the following registered practioner(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: ☐ Customer Number [ ] → *Place Customer Number Bar Code Label here*
OR
☒ Registered practitioner(s) name/registration number listed below

Name	Registration Number	Name	Registration Number
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Edward P. Heller, III	29,075	Jonathan E. Olson	41,231
Raghu Minisandram	38,683		

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])	Family Name or Surname
John F.	Heanue

Inventor's Signature	John F. Heanue					Date	1-25-00
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☒ Additional inventors are being named on the 1 supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

PTO/SB/02A (3-97)
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DECLARATION

ADDITIONAL INVENTOR(S)
Supplemental Sheet
Page 1 of 1

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

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Post Office Address							
City	Palo Alto	State	CA	ZIP	94306	Country	U.S.A.

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

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Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle [if any])				Family Name or Surname			
Inventor's Signature						Date	
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		ZIP		Country	

POWER OF ATTORNEY

Attorney Docket No.
SEA 5112

Inventor(s): John F. Heanue, John H. Jerman and Jeffrey P. Wilde

Title: WIDELY TUNABLE LASER

In the patent application:

☒ attached hereto,

☒ filed on January 26, 2000 as application Serial No. ________________.

I appoint the following attorneys to prosecute the patent application identified above and to transact all business in the Patent and Trademark Office connected therewith:

Edward P. Heller, III	Reg. No. 29,075
Raghunath S. Minisandram	Reg. No. 38,683
Shawn B. Dempster	Reg. No. 34,321
Mark A. Wardas	Reg. No. 37,961
Jonathan E. Olson	Reg. No. 41,231

I ratify all prior actions taken by Seagate Technology, Inc., or the attorneys and agents mentioned above in connection with the prosecution of the above-mentioned patent application.

I authorize Seagate Technology, Inc. to mark the appropriate space above and to insert the filing date and Serial No. of the application, as appropriate.

I authorize the U.S. attorneys named herein to accept and follow instructions from Mark A. Wardas and any person of the Intellectual Property Department of Seagate Technology, Inc. as to any action to be taken in the Patent and Trademark Office regarding this application without direct communication between the U.S. attorney and the undersigned. In the event of a change in the persons from whom instructions may be taken, the U.S. attorneys named herein will be so notified by the undersigned.

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